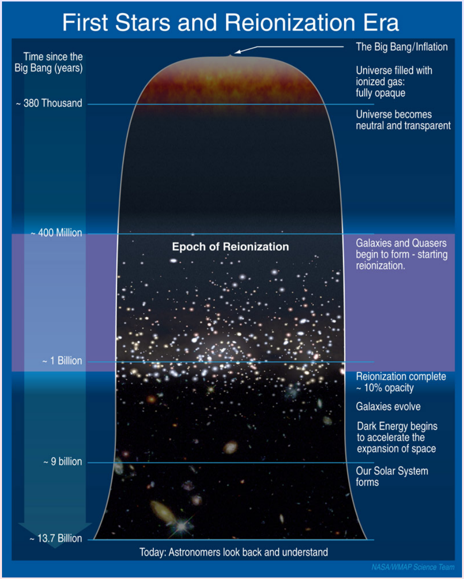
Distribution of H I in galaxies: Semi Analytic Model Approach

Jaswant K. Yadav

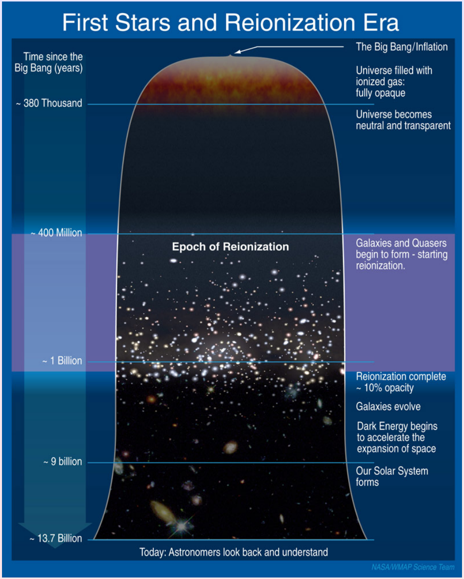
June 14, 2012

Motivation



The period of transition of IGM from neutral to ionised state is known as EoR.

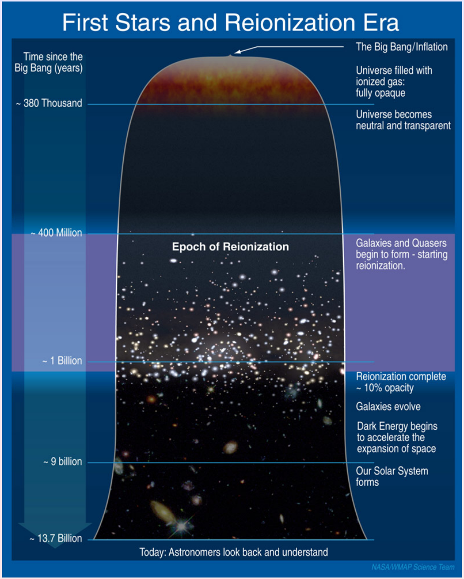
Motivation



The period of transition of IGM from neutral to ionised state is known as EoR.

Through the EoR, almost no H I left in IGM; all of H I is in ISM of galaxies.

Motivation

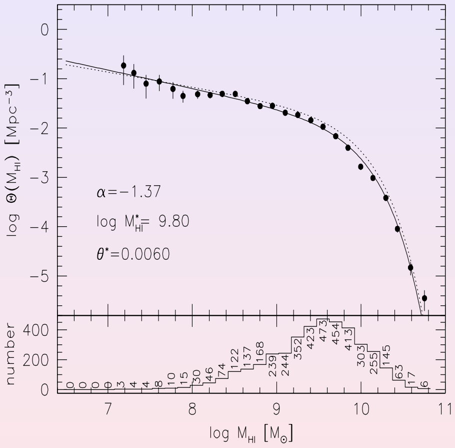


The period of transition of IGM from neutral to ionised state is known as EoR.

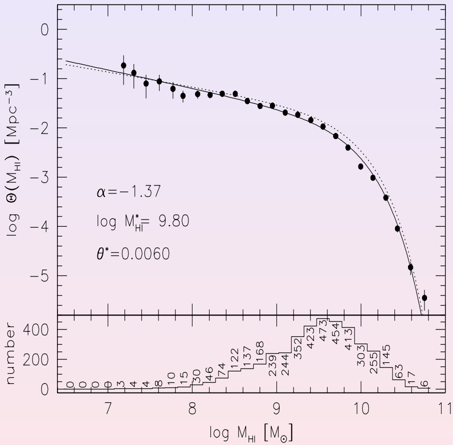
Through the EoR, almost no H I left in IGM; all of H I is in ISM of galaxies.

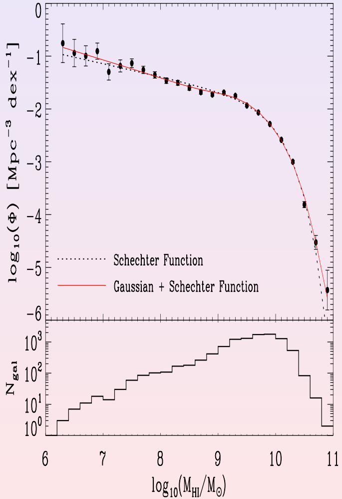
Hence, it is important to know the amount and distribution of cold gas at these redshifts.

Observation Front



Observation Front





Observation Front

HIPASS : Estimates $\Omega_{H\mathrm{I}} \sim 3.5 \times 10^{-4} h_{75}^{-1}$ in the local Universe

Observation Front

HIPASS : Estimates $\Omega_{H\mathrm{I}} \sim 3.5 \times 10^{-4} h_{75}^{-1}$ in the local Universe
ALFALFA : Extends the survey to lower mass galaxies. Updates the Schecter fit and predicts an order of magnitude more galaxies at high mass end than HIPASS. Estimates of $\Omega_{H\mathrm{I}}$ is 16% larger than HIPASS.

Observation Front

HIPASS : Estimates $\Omega_{H\text{I}} \sim 3.5 \times 10^{-4} h_{75}^{-1}$ in the local Universe
ALFALFA : Extends the survey to lower mass galaxies. Updates the Schecter fit and predicts an order of magnitude more galaxies at high mass end than HIPASS. Estimates of $\Omega_{H\text{I}}$ is 16% larger than HIPASS.
At High redshifts a quantitative estimate of the total H I content in DLAs indicate the neutral hydrogen content of the universe to be almost constant with a density parameter of $\Omega_{H\text{I}} \sim 0.001$.

Observation Front

HIPASS : Estimates $\Omega_{H\text{I}} \sim 3.5 \times 10^{-4} h_{75}^{-1}$ in the local Universe
ALFALFA : Extends the survey to lower mass galaxies. Updates the Schecter fit and predicts an order of magnitude more galaxies at high mass end than HIPASS. Estimates of $\Omega_{H\text{I}}$ is 16% larger than HIPASS.
At High redshifts a quantitative estimate of the total H I content in DLAs indicate the neutral hydrogen content of the universe to be almost constant with a density parameter of $\Omega_{H\text{I}} \sim 0.001$.
Future H I surveys will have deep impact on our understanding of galaxy formation and evolution, hence it is theoretically important to understand the outcome of currently favoured galaxy formation models w.r.t. H I in high redshift Universe.

Galaxy Formation

Objects like galaxies form when gas collapses at the center of dark matter halos after radiative cooling of baryons.(see e.g. White & Rees, 1978). There are mainly three methods to study formation and Evolution of galaxies and hence H I in ISM:

Galaxy Formation

Objects like galaxies form when gas collapses at the center of dark matter halos after radiative cooling of baryons.(see e.g. White & Rees, 1978). There are mainly three methods to study formation and Evolution of galaxies and hence H I in ISM:

- Hydrodynamic simulation

Galaxy Formation

Objects like galaxies form when gas collapses at the center of dark matter halos after radiative cooling of baryons.(see e.g. White & Rees, 1978). There are mainly three methods to study formation and Evolution of galaxies and hence H I in ISM:

- Hydrodynamic simulation
- Halo Occupation Distribution (HOD) model

Objects like galaxies form when gas collapses at the center of dark matter halos after radiative cooling of baryons.(see e.g. White & Rees, 1978). There are mainly three methods to study formation and Evolution of galaxies and hence H I in ISM:

- Hydrodynamic simulation
- Halo Occupation Distribution (HOD) model
- **Semi Analytic Modelling** : In this technique we take advantage of high resolution N-Body simulation and simple prescription for evolution of baryons in dark matter halos

N- Body Simulations

$L_{\rm box}$	$N_{\rm part}$	$m_{\rm part}$	z^f	$n_{\rm snap}$
23.04	512^3	6.7×10^6	5.0	24
51.20	512^3	7.0×10^7	3.0	29
76.80	512^3	2.3×10^8	1.0	19
153.6	512^3	7.5×10^9	0.0	23

FoF algorithm used to identify halos.

- Index of the *central particle* of each halo, which is the most-bound particle in the halo.
- The *virial mass* of the halo $\mathbf{M}_{\rm vir} = \mathbf{m}_{\mathbf{part}} \times \mathbf{N}_{\mathbf{part,Halo}}$
- The *virial radius* of the halo $\mathbf{R}_{\rm vir} = (\mathbf{GM}_{\rm vir}/\mathbf{100H^2})^{\mathbf{1/3}}$.
- The *circular velocity* of the halo at virial radius $\mathbf{V_c} = (\mathbf{GM}_{\rm vir}/\mathbf{R}_{\rm vir})^{\mathbf{1/2}}$.

▸ Results ▸ Model

SAM Calibration : Local TF Relation

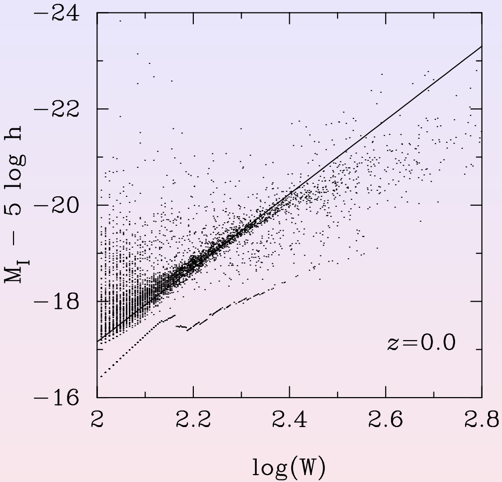


Figure: Local Tully-Fisher Relation for model galaxies compared with observation of Giovanelli et al. 1997 (Kulkarni,JKY,Bagla; Submitted)

SFR density

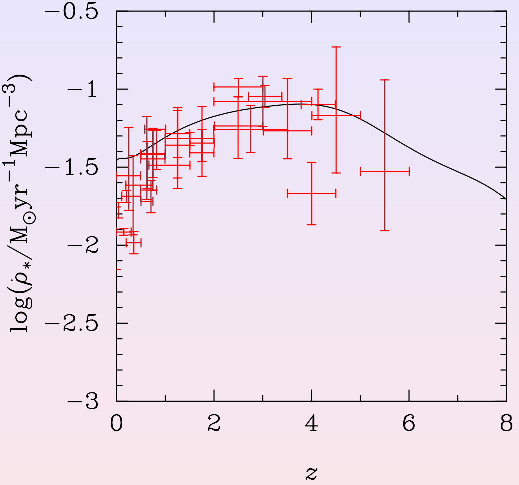


Figure: Data points with error bars are from a compilation of observations as in Springel & Hernquist 2003

The black hole M - σ relation

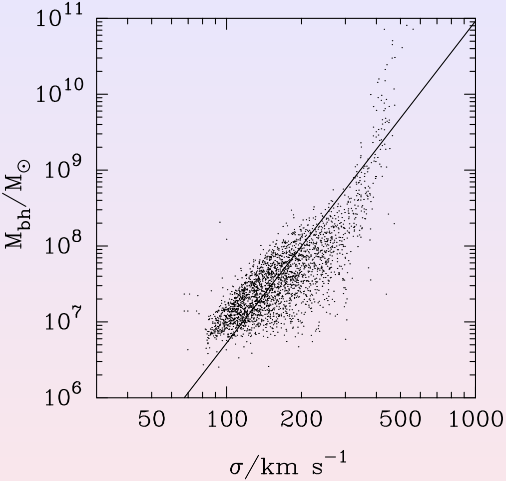


Figure: The $M_{\rm bh} - \sigma$ relation of our model galaxies compared to observations by Kayhan et. al 2009

Luminosity function (without dust extinction)

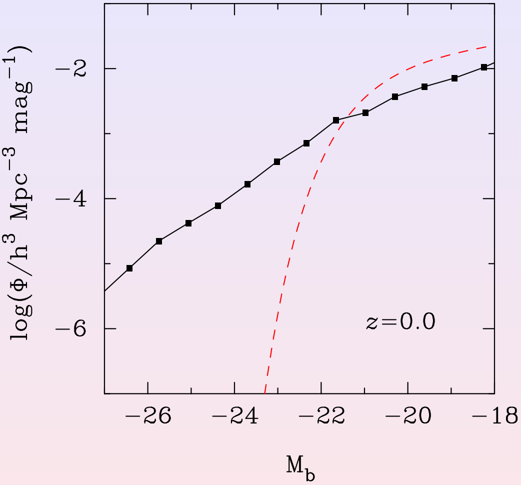
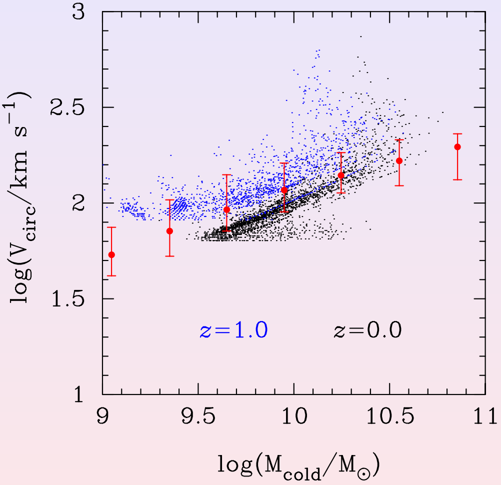


Figure: The B-Band Luminosity function

Cold gas versus Circular Velocity



Cosmic density of H I

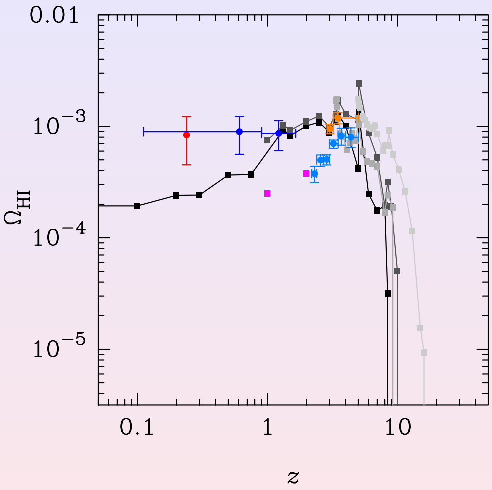


Figure: Evolution of HI mass density

Cold gas fraction of haloes in our simulation

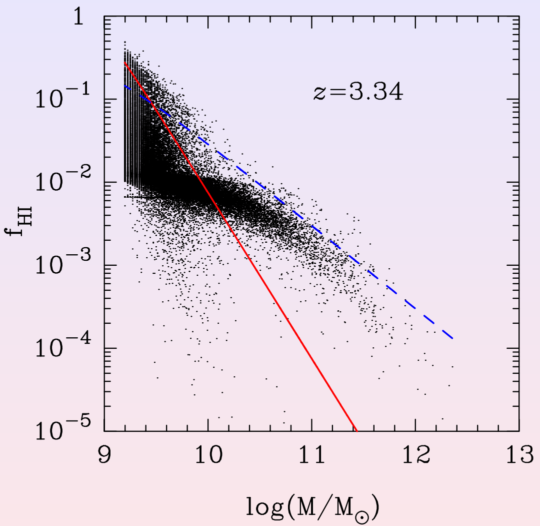


Figure: Model comparison with previous works

Power Spectrum and Bias

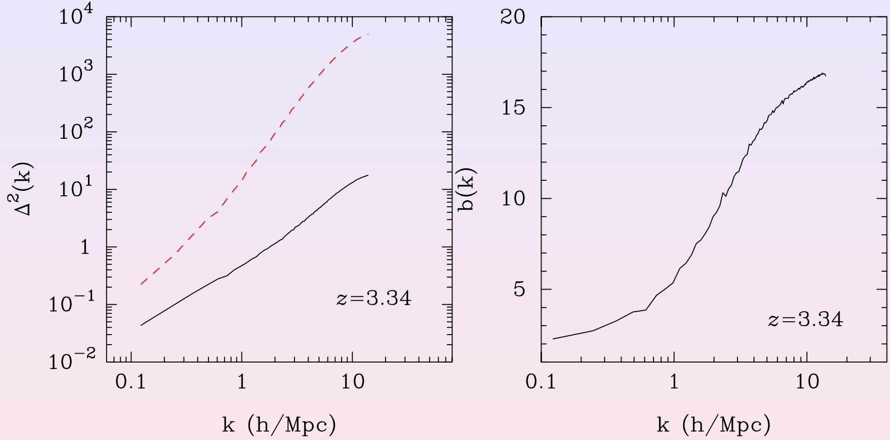


Figure: Power spectra in our model at z = 3.34. Black solid is dark matter and red dashed is HI. Right panel is HI bias

Power Spectrum and Bias Evolution

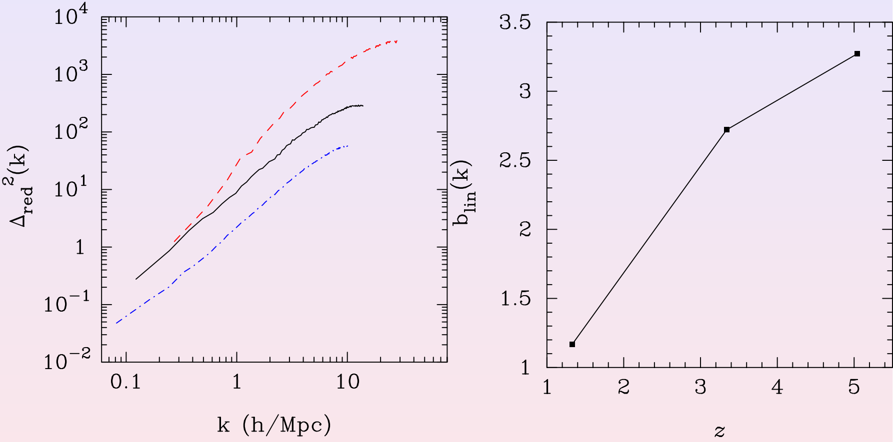


Figure: Blue is z=1.3, black is z=3.34 and red is z=5.1

Conclusions

- An improved and self consistent calculation of H I in galaxies is presented using a semi analytical code of galaxy formation (Kulkarni,JKY & Bagla, Submitted)
- We find that the clustering of HI at small scales is very strong, stronger than what was found in simple models presented earlier.
- This reinforces the point that direct detection of rare peaks in the HI distribution may require less time that statistical detection at larger scales.
- Further studies are required to refine strategies for HI detection in the post-reionization epochs.

▸ End

SAM Implementation

- A merger tree is constructed by connecting DM Halos across different epochs of simulation.
- Starting from the highest redshift, on each branch of merger tree the simple recipes of SAM are applied.
- The main processes to model are Cooling,SFR and Feedback mechanisms.

Gas Cooling

Before the structure forms the gas has the same distribution as DM.

$$T_v = 35.9(V_c/kms^{-1})^2 K \quad (1)$$

1. Cooling by IC scattering of CMB photons by electrons. Not effective at late times.
2. $T_v < 10^4 K$: Deexcitation of fine structure lines of heavy elements and rotational levels of molecules.
3. $10^4 K < T_v < 10^{7.5} K$: Decay through the recombination of electron and ions. Much dependent on metallicity.
4. $T_v > 10^{7.5} K$: Bremsstrahlung emmision. Cooling dominated by free-free transition in elctron-ion collision.

Cooling efficiency also depends on size of Halos.

$$\dot{M}_* = \alpha M_{cold} / t_{dyn} \tag{2}$$

In Spherical Collapse Model
$R_{vir} \propto V_c(1+z)^{-3/2}$

- Halos are smaller and Denser at Earlier Epochs
- SFR is higher in Halos at Earlier z, even for same cold gas

Feedback From Supernovae

Supernovae reheat the cold gas and may drive a wind.

$$\Delta m_{\rm reheated} = \epsilon_{\rm gal} \Delta m_* \qquad (3)$$

Energy in SN ejecta

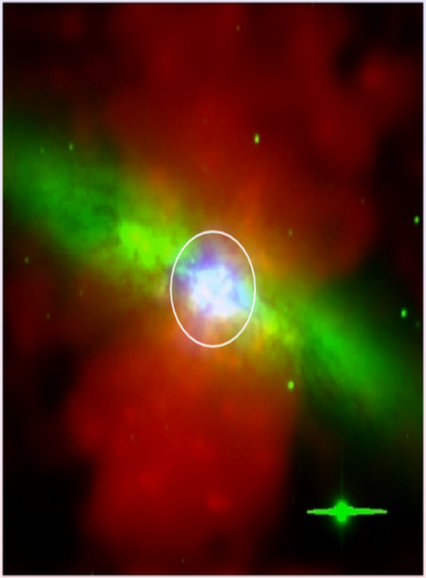
$$\Delta E_{\rm SN} = 0.5 \epsilon_{\rm halo} \Delta m_* V_{\rm SN}^2, \qquad (4)$$

Change in thermal Energy of halo

$$\Delta E_{\rm hot} = 0.5 \Delta m_{\rm reheated} V_{\rm vir}^2. \qquad (5)$$

Condition for reheated gas to eject from the hot component

$$\Delta E_{\rm excess} = \Delta E_{\rm SN} - \Delta E_{\rm hot}. \qquad (6)$$



Feedback From AGN

Increase in mass of BH in mergers

$$\Delta m_{\mathrm{BH,Q}} = \frac{f'_{\mathrm{BH}} m_{\mathrm{cold}}}{1 + (200\,\mathrm{km\,s^{-1}}/V_{\mathrm{vir}})^2} \quad (7)$$

Accretion due to Radio mode of feedback

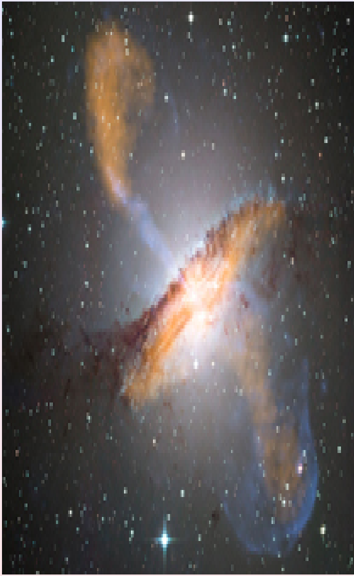
$$\dot{m}_{\mathrm{BH}} = \kappa \left(\frac{m_{\mathrm{BH}}}{10^8 \mathrm{M}_{\odot}}\right) \left(\frac{f_{\mathrm{hot}}}{0.1}\right) \left(\frac{V_{\mathrm{vir}}}{200\ kmps}\right)^3$$

Mechanical heating generated by this mode

$$L_{\mathrm{BH}} = \eta \dot{m}_{\mathrm{BH}} c^2, \quad (8)$$

This modifies the cooling rate to

$$\dot{m}'_{\mathrm{cool}} = \dot{m}_{\mathrm{cool}} - 2 L_{\mathrm{BH}}/V_{\mathrm{vir}}^2 \quad (9)$$



▸ Results

Thank You for your Attention.